Year: 2018

Augmented Reality-Guided Lumbar Facet Joint Injections

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Abstract: OBJECTIVES The aim of this study was to assess feasibility and accuracy of augmented reality-guided lumbar facet joint injections. MATERIALS AND METHODS A spine phantom completely embedded in hardened opaque agar with 3 ring markers was built. A 3-dimensional model of the phantom was uploaded to an augmented reality headset (Microsoft HoloLens). Two radiologists independently performed 20 augmented reality-guided and 20 computed tomography (CT)-guided facet joint injections each: for each augmented reality-guided injection, the hologram was manually aligned with the phantom container using the ring markers. The radiologists targeted the virtual facet joint and tried to place the needle tip in the holographic joint space. Computed tomography was performed after each needle placement to document final needle tip position. Time needed from grabbing the needle to final needle placement was measured for each simulated injection. An independent radiologist rated images of all needle placements in a randomized order blinded to modality (augmented reality vs CT) and performer as perfect, acceptable, incorrect, or unsafe. Accuracy and time to place needles were compared between augmented reality-guided and CT-guided facet joint injections. RESULTS In total, 39/40 (97.5%) of augmented reality-guided needle placements were either perfect or acceptable compared with 40/40 (100%) CT-guided needle placements ($P = 0.5$). One augmented reality-guided injection missed the facet joint space by 2 mm. No unsafe needle placements occurred. Time to final needle placement was substantially faster with augmented reality guidance (mean 14 ± 6 seconds vs 39 ± 15 seconds, $P < 0.001$ for both readers). CONCLUSIONS Augmented reality-guided facet joint injections are feasible and accurate without potentially harmful needle placement in an experimental setting.

DOI: https://doi.org/10.1097/RLI.0000000000000478

Originally published at:
Agten, Christoph A; Dennler, Cyrill; Rosskopf, Andrea B; Jaberg, Laurenz; Pfirrmann, Christian W A; Farshad, Mazda (2018). Augmented Reality-Guided Lumbar Facet Joint Injections. Investigative Radiology, 53(8):495-498.
DOI: https://doi.org/10.1097/RLI.0000000000000478

Augmented Reality–Guided Lumbar Facet Joint Injections

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Objectives: The aim of this study was to assess feasibility and accuracy of augmented reality–guided lumbar facet joint injections.

Materials and Methods: A spine phantom completely embedded in hardened opaque agar with 3 ring markers was built. A 3-dimensional model of the phantom was uploaded to an augmented reality headset (Microsoft HoloLens). Two radiologists independently performed 20 augmented reality–guided and 20 computed tomography (CT)–guided facet joint injections each: for each augmented reality–guided injection, the hologram was manually aligned with the phantom container using the ring markers. The radiologists targeted the virtual facet joint and tried to place the needle tip in the holographic joint space. Computed tomography was performed after each needle placement to document final needle tip position. Time needed from grabbing the needle to final needle placement was measured for each simulated injection. An independent radiologist rated images of all needle placements in a randomized order blinded to modality (augmented reality vs CT) and performer as perfect, acceptable, incorrect, or unsafe. Accuracy and time to place needles were compared between augmented reality–guided and CT-guided facet joint injections.

Results: In total, 39/40 (97.5%) of augmented reality–guided needle placements were either perfect or acceptable compared with 40/40 (100%) CT-guided needle placements ($P = 0.5$). One augmented reality–guided injection missed the facet joint space by 2 mm. No unsafe needle placements occurred. Time to final needle placement was substantially faster with augmented reality guidance (mean 14 ± 6 seconds vs 39 ± 15 seconds, $P < 0.001$ for both readers).

Conclusions: Augmented reality–guided facet joint injections are feasible and accurate without potentially harmful needle placement in an experimental setting.

Key Words: augmented reality, lumber fact joints, injections, spine, phantom, mixed reality

(*Invest Radiol* 2018;00: 00–00)

Augmented reality rapidly evolves due to fast-developing technology and has a huge potential in medicine. Augmented reality is defined as the real-time integration of computer-generated information in a user's environment. This can be images, sounds, or any other data. In medicine specifically, augmented reality most often refers to superimposition of virtual images to a user's view. These concepts were already discussed in the field of medicine as early as 1995.[1,2] Recent technical developments with wearable augmented reality devices, such as Microsoft's HoloLens, generated a lot of interest, and augmented reality is now known to a wider audience. Microsoft's HoloLens is a headset with an integrated holographic computer that allows spatial projection of 3-dimensional holograms within an observed environment, which are only visible through the headset.[3] This technology is also referred to as mixed reality to separate it from augmented reality; sometimes both terms are used interchangeably, depending on the definition. For the purposes of this study, we used the term augmented reality.

The possibility to superimpose real-time images or 3-dimensional structures to a user's view provides many applications in radiology, such as imaging-guided interventions.[4,5] The real-time overlay of a patient's anatomical structures to its actual body may omit the need of radiation-dependent imaging guidance systems such as fluoroscopy or computed tomography (CT)–fluoroscopy. Not only would this reduce radiation dose to the patient, but also to the performing radiologist. As the clinical application of augmented reality in patient treatment still faces some technical challenges, we opted to proof the feasibility of augmented reality–guided interventions using HoloLens in a phantom study. Lumbar facet joint injections are typically performed either with fluoroscopy guidance or with CT guidance. These injections are easy to perform and safe, however, with radiation exposure to the patient and the physician. The purpose of our study was to assess feasibility and accuracy of augmented reality–guided lumbar facet joint injections.

MATERIALS AND METHODS

We built a spine phantom using 2 articulating sawbone lumbar vertebrae, completely embedded in hardened opaque agar. We attached 3 ring markers (adhesive tape) to the phantom container (Fig. 1A). A CT scan of the phantom was acquired (Somatom Definition AS; Siemens Healthineers, Erlangen, Germany) at 120 kV, with a slice-thickness of 1 mm (window width, W = 400 HU; window center, C = 60 HU). The DICOM files of this CT scan were then loaded into a segmentation tool (syngo.via, 3D Printing; Siemens Healthineers CT version 1.2.0, Erlangen, Germany). We created a virtual 3-dimensional model (STL [standard tessellation language] file) of our phantom using density-based segmentation techniques, only showing the 2 articulating vertebrae and the 3 ring markers. This 3-dimensional model was then uploaded to our augmented reality headset (Microsoft HoloLens; Microsoft Corp, Redmond, WA) using the recommended software development tools as described in the technical documentation.[6]

Two fellowship-trained musculoskeletal radiologists (C.A. and A.R., with 8 and 11 years of experience), independently performed 20 facet joint simulated injections each, only with the use of HoloLens: for each facet joint injection, the holographic projection (hologram) of the phantom was manually aligned with the phantom container using the 3 ring markers as reference (Fig. 1B). Once perfectly aligned by the radiologist's judgment (visual match of virtual and real ring markers through the headset), the radiologists targeted the virtual facet joint to place a 10.6-cm long 16-gauge needle (Angiotech Co-axial introducer needle; Medical Device Technologies, Inc, Gainesville, FL) into the virtual facet joint and presumably in the real facet joint of the phantom (Fig. 1) that was not visible due to the opaque agar gel. The radiologists were allowed to adjust the needle if they suspected a suboptimal needle placement. We performed a CT scan after each needle placement to document the needle tip position. For each injection, a new sheath of paper was placed on the surface of the phantom to obscure prior injection markers in the agar gel.

Both radiologists also performed 20 CT-guided facet joint injections in the same phantom with CT (intermittent CT guidance) guidance (Somatom Definition AS; Siemens Healthineers, Erlangen, Germany), just as we do lumbar facet joint injections in our clinical routine. Hence,

Received for publication December 19, 2017; and accepted for publication, after revision, March 18, 2018.

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Conflicts of interest and sources of funding: none declared.

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ISSN: 0020-9996/18/0000–0000
DOI: 10.1097/RLI.0000000000000478

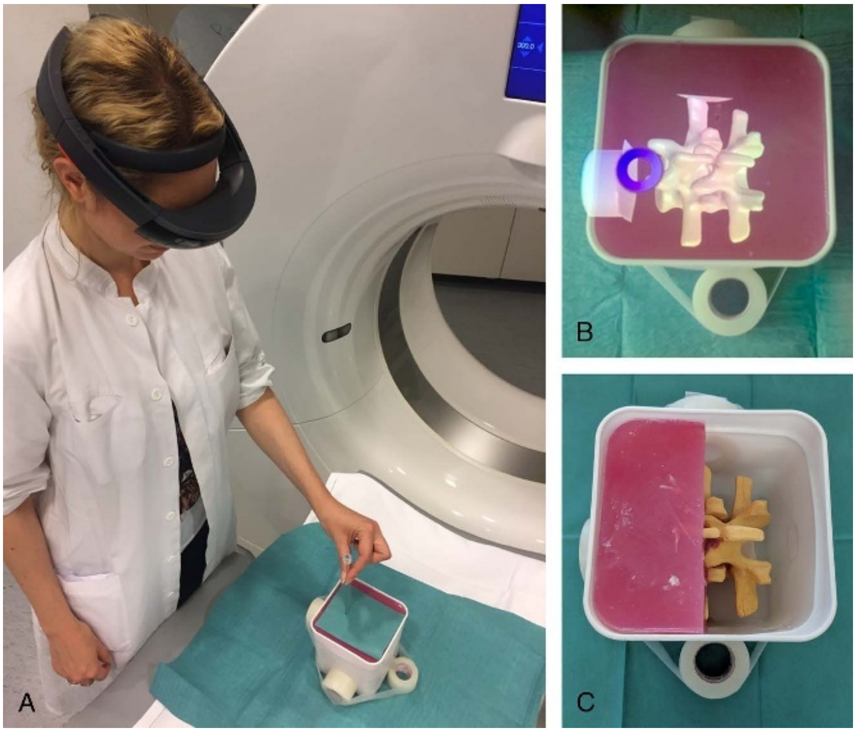

FIGURE 1. Radiologist performing an augmented reality–guided facet joint injection (A). Photo from the radiologist's point of view through the HoloLens shows the hologram inside the phantom container (B). Only the holographic ring marker to the left is visible in this photo, due to a limited field of view. The blue ring is the HoloLens live cursor. Last image shows partially released sawbone vertebral bodies in agar (C).

the radiologists could acquire CT images using a pedal on the floor just next to the scanner (same room) during needle placement and adjust needle placement until a satisfactory position was achieved. Again, final needle placement was documented with CT. All injections were performed on the same day in 1 session.

For augmented reality–guided and CT-guided facet joint injections, we measured the time from grabbing the needle until the radiologist indicated final needle placement using a stopwatch.

An independent third musculoskeletal radiologist (C.P., with 20 years of experience) rated all CT scans that documented needle placement in a randomized order blinded to modality (augmented reality vs CT) and performer as follows: perfect needle placement (needle tip exactly in facet joint space), acceptable needle placement (rater would accept injection at this position), incorrect needle placement (rater would correct needle tip position before injection), and unsafe needle placement (needle in a potentially dangerous location such as near nerve roots or spinal canal). Accuracy and time to place needles were compared between augmented reality–guided and CT-guided facet joint injections (Mann-Whitney *U* test). A *P* value of 0.05 was set to indicate a statistically significant difference. We used IBM SPSS Statistics (IBM Corp, Version 24, IBM, Armonk, NY) for all statistical analyses.

RESULTS

In total, 39/40 (97.5%) of augmented reality–guided needle placements were either perfect or acceptable compared to 40/40 (100%) CT-guided needle placements ($P = 0.5$; Fig. 2). Accuracy of augmented reality–guided injections was not statistically significantly different compared to CT-guided injections (Table 1). The only incorrect needle tip placement in the augmented reality group missed the facet joint space by only 2 mm (Fig. 3). No unsafe needle placements occurred. Time to final needle placement was substantially faster with augmented reality guidance (mean 14 ± 6 seconds vs 39 ± 15 seconds, $P < 0.001$ for both readers).

DISCUSSION

Augmented reality–guided facet joint injections were accurate without potentially harmful needle placement in our experimental setting. Only 1 needle tip was rated as incorrectly placed. However, this needle tip only missed the facet joint space by 2 mm and would have been well inside the joint capsule. Hence, depending on the performer, even that position may be suitable for injection. One problem we faced

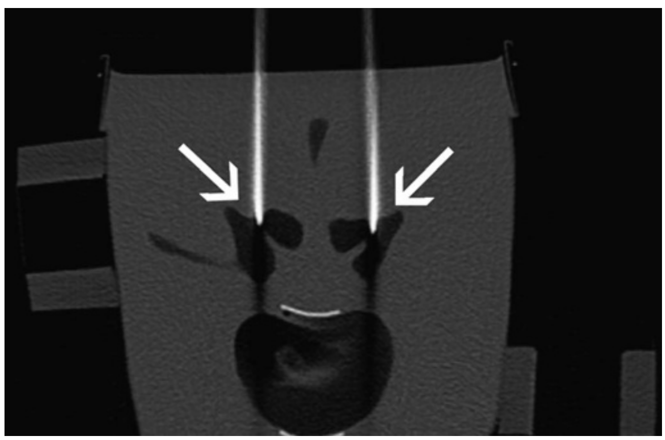

FIGURE 2. Computed tomography image of the spine phantom after augmented reality–guided facet joint injection with perfect needle placement (white arrows). Vertebral body appears hypodense due to the used sawbone material.

TABLE 1. Accuracy of Augmented Reality–Guided and CT-Guided Facet Joint Injections

		Modality		
		AR	**CT**	***P***
Radiologist 1	Perfect	13	16	0.398
	Acceptable	6	4	
	Incorrect	1	0	
	Unsafe	0	0	
	Total	20	20	
Radiologist 2	Perfect	17	19	0.602
	Acceptable	3	1	
	Incorrect	0	0	
	Unsafe	0	0	
	Total	20	20	

AR indicates augmented reality; CT, computed tomography.

was the manual alignment of the hologram and the phantom. Although we did not measure the time needed for sufficient alignment, this was sometimes a tedious process. Inaccurate hand gestures to move the hologram or problems with voice commands to control HoloLens contributed to this. However, these are technical obstacles that most likely will be overcome in the years to come, as the ultimate goal is a fully automatic object-hologram registration. Once the object and holograms are automatically registered, this elaborate process will not be necessary anymore.

We chose lumbar facet joints because the injection technique is easy and therefore accuracy of the needle placement less dependent on technical skills by the performer but rather by the imaging guidance system. The completely agar-embedded phantom provided us with a good approximation of real patients, simulating lumbar soft tissues. Based on our phantom study, we would be confident enough to apply this in patients, but the time-consuming 3-dimensional model generation and elaborate manual alignment currently do not allow implementation of augmented reality–guided lumbar facet joint injections in the clinical routine yet.

This study nicely demonstrates current problems in augmented reality–guided interventions. The main issue is the alignment of the hologram and the real object (patient). If this registration is incorrect, even by 1 to 2 mm, based on the intervention, this would have potentially important consequences. Another issue that we encountered was subtle movement of the hologram when the user wearing the headset moved his or her head. This is due to a known imprecision of the spatial mapping of the Hololens, which certainly will be improved in future versions. At the time, this subtle movement sometimes required that the performing radiologist had to realign the hologram when he noted a spatial drift. Nevertheless, the high accuracy of our injections is impressive considering these technical limitations. Future iterations of the wearable hardware and software should improve this movement and registration problems.

One interesting finding in our study was that the HoloLens-guided injections were markedly faster than the CT-guided injections. One reason is that both radiologists were sometimes not fully satisfied with the needle position on the control CT and then needed additional time to correct the needle position. In contrast, the needle tip using augmented reality guidance was not visible to the performer and they had to rely on the trajectory of the needle to estimate the needle tip position. However, in a clinical setting, once the needle would be inserted using augmented reality, one could do an additional CT image to proof correct needle placement before injecting medication. In our phantom study, we were obviously not injecting any liquid, as we used the same phantom for all injections. Once technical limitations of augmented reality are solved, this technique would allow performing lumbar facet joint injections without any radiation to the performing radiologist.

There are published studies using alternative augmented reality techniques in radiology. Fritz et al[4] used an augmented reality image overlay system for magnetic resonance imaging–guided arthrography for the shoulder and hip in cadavers. All their injections were intra-articular. However, their prototype system was bulky and only a 2-dimensional image overlay was used. The advantage of a 2-dimensional image overlay system is that no segmentation is necessary, as it uses the cross-sectional images for guidance. This also allows targeting any structure visible on these images, while this is more difficult when density-based segmentation needs to be applied for 3-dimensional holograms. The same group used the same technique for a variety of other magnetic resonance imaging–guided procedures, such as paravertebral plexus injections,[7] vertebroplasty,[8] bony biospy,[9] and different spine injections.[10] Others used augmented reality surgical navigation systems combining ultrasound and CT data for pedicle screw placement[11] or for needle biopsies in an animal model.[12] The size and cost of such overlay systems has been reduced significantly. Although the costs of the larger system mentioned earlier were reported as $4000,[5] a smaller version using a portable tablet-based augmented reality image overlay guidance system has been presented, further reducing costs.[13] In addition, they used the software 3D slicer,[14] which is freely available. Microsoft Hololens starts at $3000.[3] The segmentation software we used is not freeware. However, any software that allows to create *.STL files from DICOM data should be suitable. Clinical studies using new generation holographic devices such as HoloLens are scarce, and therefore, comparison of our results with other data is limited. The Microsoft HoloLens system was recently tested in an anatomic pathology study for different applications in pathology, for example, remote supervision of autopsy, annotation of anatomic structures, and telepathology.[15]

Our study had limitations. First, we had to use a larger needle than we do in clinical routine. The reason was that our standard 20- to 22-gauge needles have a relatively large bevel at the tip. This bevel ultimately influences the direction of the needle while pushing forward, due to the consistency of the agar. Hence, we used a needle with a round tip, so that the needle morphology would not impact the trajectory of the needle. Second, we did not measure radiation, as the purpose of this study was to assess accuracy. The radiation dose will become relevant once we apply augmented reality to real patients. However, in our experiment, radiologists were not exposed to radiation during the augmented

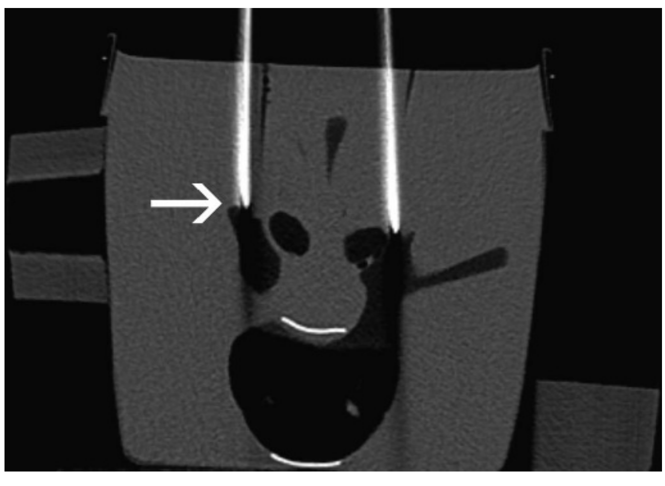

FIGURE 3. Computed tomography image of the spine phantom after augmented reality–guided facet joint injection with the only incorrect needle placement on the left side (white arrow). Vertebral body appears hypodense due to the used sawbone material.

reality–guided injections, but needed to wear protective gear during the CT-guided injections. Currently, in our practice, radiologists stay in the CT room during CT-guided procedures and use a foot pedal for intermittent CT guidance.

In conclusion, augmented reality–guided facet joint injections are accurate without potentially harmful needle placement in an experimental setting. Ongoing research is currently solving technical limitations such as the time-consuming processing, manual alignment, and misregristration during patient movement. Soon, augmented reality may allow such interventions faster, without radiation exposure to the performing radiologist, and with potentially less radiation for patients.

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